ON IMPROVEMENT OF ACCURACY OF AIRBORNE LASER SCANNER DATA USING DIGITAL IMAGES

Kazuya NAKANO [a*], Hirofumi CHIKATSU [b*]

[a] System Development Group, AERO ASAHI CORPORATION,
3-1-1, Minamidai, Kawagoe, Saitama, 350-1165, Japan - kazuya-nakano@aeroasahi.co.jp
[b] Dept. of Civil and Environmental Engineering, Tokyo Denki University,
Ishizaka, Hatoyama, Saitama, 350-0394, Japan - chikatsu@g.dendai.ac.jp

Commission I, WG I/2

KEYWORDS: LIDAR, Integration, Aerial Photogrammetry, GPS/INS, Bundle Adjustment, Georeferencing

ABSTRACT:

Airborne laser scanner is useful system for acquiring point clouds 3D data with real-time, and it came to be generally used in the late 1990s. Airborne laser scanner have effectiveness in extracting micro topography or ground surface under the trees which are not detect by photogrammetry, and many applications such as city modelling, DTM generation, monitoring electrical power lines and detection of forest areas were proposed. The most remarkable point of this system, however, is its ability to obtain 3D coordinates of huge object points with real-time. Airborne Laser Scanner is basically based on GPS, inertial measurement unit (IMU) and laser scanning device (Laser Rangefinder). GPS and IMU provide position and attitude information regarding trajectory of platform, and laser scanning device give distance between platform and the object points. Therefore, direct-georeferencing system using GPS/IMU comes to be utilized widely in the field of aerial photogrammetry, nevertheless matching among stereo models and courses are not adjusted since the direct-georeferencing system are influenced by cycle-slip and satellite placement. This paper investigates fundamental studies to improve of accuracy of airborne laser scanner data using digital images.

1. INTRODUCTION

Airborne laser scanner came to be generally used for terrain measurement from the view point of prominent characteristic (Baltsavias, 1999). Airborne laser consists of 2 key technologies as spin-off of military technology; one is GPS/IMU (i.e. direct-georeferencing), other is laser scanning device. Current paradigm shift of platform orientation was caused by direct-georeferencing using GPS/IMU nevertheless system calibration in GPS/IMU system is the most critical factor (Cramer and Stallmann, 2002).

In order to control quality of aerial photogrammetry using GPS/IMU system, Geographical Survey Institute (GSI) prescribe establishments of several ground control points and practice of aerial triangulation in generating large scale maps such as 1/1,000. GSI also prescribe mechanical accuracy such as ±30 cm accuracy for GPS by continuous kinematic, and rolling and pitching accuracy are 0.013 degrees, heading is 0.035 degrees for IMU respectively.

In the meantime, GSI has established 1,224 GPS stations all over the country for monitoring of the crustal movement. Then, it become possible to utilize these GPS stations for quality control of airborne laser scanner data, and GSI prescribe mechanical accuracy as same as the aerial photogrammetry so that ±25 cm accuracy are achieved in vertically by airborne laser scanner.

On the contrary, take into account that the direct-georeferencing system are influenced by cycle-slip and satellite placement, some adjustment for the direct-georeferencing system in airborne laser scanner should be considered as well as establishment of several ground control points and practice of aerial triangulation in the aerial photogrammetry using GPS/IMU.

In order to improve the issues such as cycle-slip and satellite placement in the direct-georeferencing system, simultaneous adjustment combined with aerial photogrammetry and airborne laser scanner become possible under consideration of current situation that non-metric digital camera is equipped with airborne laser scanner system. However, previous interior orientation procedure newly comes up as the another issue since interior orientation procedure for non-metric digital camera is generally performed beforehand using test sheet or test target, and the previous interior orientation procedure should be removed for ideal direct-georeferencing system.

With this motive, simultaneous adjustment such as bundle adjustment with self-calibration is proposed in this paper so that exterior orientation parameters which are obtained from GPS/IMU system, 3D objects coordinate which are acquired from laser scanner and the interior orientation parameters are adjusted simultaneously. Though, the combined orientations in block adjustment had been proposed in late 1900's (Ackermann, & et al., 1972, EL-Hakim & Faig, 1981, Chikatsu, & et al., 1988), it is enormously expected that the proposed adjustment will make possible to utilize airborne laser scanner in generating large scale map, and efficient aerial photogrammetry except the geodetic data such as ground control points and the aerial triangulation will be accomplished.

2. WORKFLOW

In order to achieve the simultaneous adjustment, brief procedures which are investigated in this paper are as follows.

・Acquisition of Approximate Values
+ Approximate values for trajectory of platform are calculated by post processing using GPS and IMU.
+ Approximate values for exterior orientation parameters are given from direct-georeferencing system.
+ Nominal values for interior orientation parameters such as focal length, principal points and so on are adopted as initial values.
+ Coarse point clouds 3D data are generated using the trajectory values and exterior orientation parameters.

・Camera Calibration
+ Bundle adjustment with self-calibration is performed using coarse point clouds 3D data.
+ Trajectory of platform is recalculated by GPS/IMU and calibration results.

・Generating DSM
+ All point clouds data are corrected using recalculated trajectory of platform.
+ DSM is generated.

3. CAMERA CALIBRATION

The authors have been concentrating on developing a close range measurement system for consumer grade digital cameras using triplet images (Chikatsu & et al., 2006). The measurement system was adopted into digital aerial photogrammetry in this paper since triplet images have following characteristics.

+ Triplet images have advantages in generating stereo pairs.
+ Triplet images have flexibility for multiple images.
+ Triplet images have ability to increase geometric restriction.

On the other hand, lens distortion is the most important parameter among interior orientation parameters, and many distortion models were proposed (Fryer and Brown, 1986). In order to apply consumer grade digital cameras to digital photogrammetry, it was concluded that lens distortion was corrected sufficiently using radial polynomial 5th degree model (Chikatsu, 2007). Therefore, radial polynomial 5th degree was adopted in this paper, and accuracy performances for the simultaneous adjustment were investigated regarding following calibrations models.

3.1 Calibration using Pseudo GCPs

Pseudo GCP is interesting points on the image and Pseudo GCPs have following advantage.

- It doesn't require for Pseudo GCPs as initial value to have accurate coordinate.
- Pseudo GCPs can be extracted as a feature point on the image.
- 3D coordinates for Pseudo GCPs are computed from point clouds data.

Therefore, camera calibration using pseudo GCPs was considered as primary stage for the simultaneous adjustment.
Figure 1 shows concept of generating pseudo GCP, and X,Y,Z coordinate for the Pseudo GCPs are computed by following procedures.

+ Interesting points such as edge of road paint are extracted as a feature point on the image, and the image coordinates are acquired.
+ Initial ground coordinates of the interesting points are calculated using the image coordinates, initial interior parameters and exterior orientation parameters which are obtained from direct-georeferencing.
+ Point clouds data (*X, Y, Z*) around the interesting point are transformed to image coordinates (*u, v*) by collinearity equation (1).
+ Positional relationship between the pseudo GCP and the point clouds on the image are computed using each image coordinate.
+ Heights of the interesting points (the pseudo GCPs) were computed from weighted interpolation equation (2).
+ Two-dimensional coordinates of the interesting points (the pseudo GCPs) were computed from equation (3).

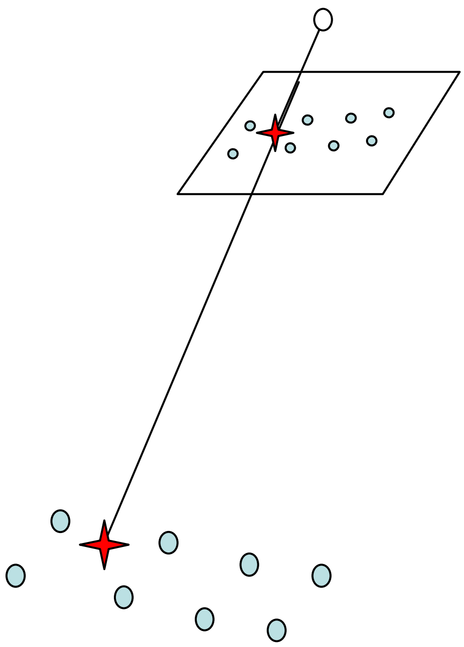

Figure 1. Concept of pseudo GCP

$$u = -f\frac{a_{11}(X-X_0)+a_{12}(Y-Y_0)+a_{13}(Z-Z_0)}{a_{31}(X-X_0)+a_{32}(Y-Y_0)+a_{33}(Z-Z_0)}$$
$$v = -f\frac{a_{21}(X-X_0)+a_{22}(Y-Y_0)+a_{23}(Z-Z_0)}{a_{31}(X-X_0)+a_{32}(Y-Y_0)+a_{33}(Z-Z_0)} \quad (1)$$

where u, v: image coordinates
f: focal length
a_{ij} : rotation matrix
X, Y, Z: ground coordinates of the point clouds
X_0, Y_0, Z_0: exposure station

$$\overline{Z} = \frac{\sum w_i Z_i}{\sum w_i} \qquad w_i = \frac{1}{\sqrt{(u - u_i)^2 + (v - v_i)^2}} \tag{2}$$

Where Z_i:height of the point clouds
u_i, v_i:image coordinates of the point clouds
$\overline{Z}$: hight of the interesting point
u, v: image coordinates of the interesting point

$$u = -f\frac{a_{11}(X - X_0) + a_{12}(Y - Y_0) + a_{13}(Z - Z_0)}{a_{31}(X - X_0) + a_{32}(Y - Y_0) + a_{33}(Z - Z_0)} \qquad v = -f\frac{a_{21}(X - X_0) + a_{22}(Y - Y_0) + a_{23}(Z - Z_0)}{a_{31}(X - X_0) + a_{32}(Y - Y_0) + a_{33}(Z - Z_0)} \tag{3}$$

where u, v: image coordinates
f : focal length
a_{ij} : rotation matrix
X, Y, Z: ground coordinates of interesting point
X_0, Y_0, Z_0: exposure station of platform

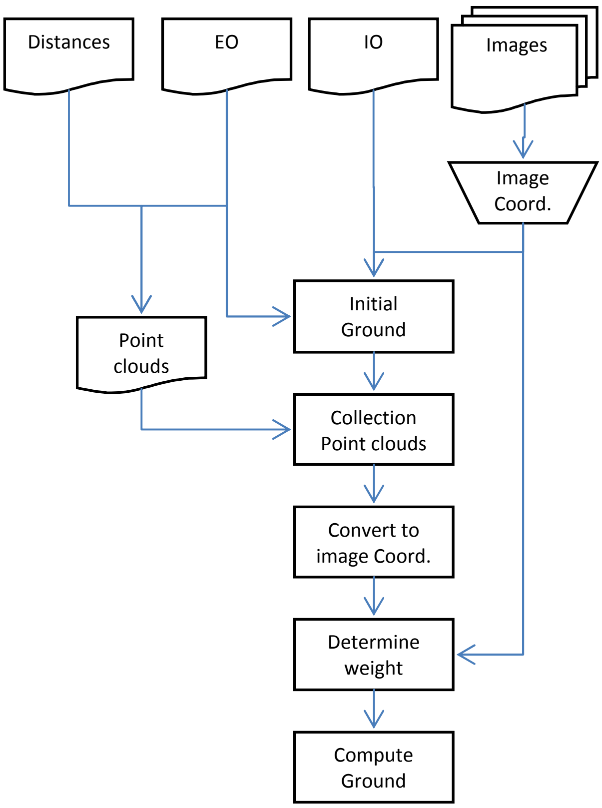

Figure 2. Flowchart of pseudo GCPs generation

3.2 Simultaneous adjustment

In order to improve the calibration accuracy, triplet restriction was adopted into the calibration using Pseudo GCPs. Due to the triplet images were generated 3 stereo pairs, interesting point P(X,Y,Z) has different 3 ground coordinates for each stereo pairs which are shown in Figure 3.
Therefore, triplet restriction was applied so that the each residual ΔP for the X,Y,Z become minimum in calibration procedures. Here, each residual ΔP are computed from equation (4).

$$\Delta P_{AB} = P_{ave.} - P_{AB} \qquad \Delta P_{BC} = P_{ave.} - P_{BC} \qquad \Delta P_{AC} = P_{ave.} - P_{AC} \qquad P_{ave.} = \frac{\sum W_i P_i}{\sum W_i} \tag{4}$$

where, P_{ij}:ground coordinates of the interesting point
ΔP_{ij} : differences of each stereo pair
W_i:weight of each point

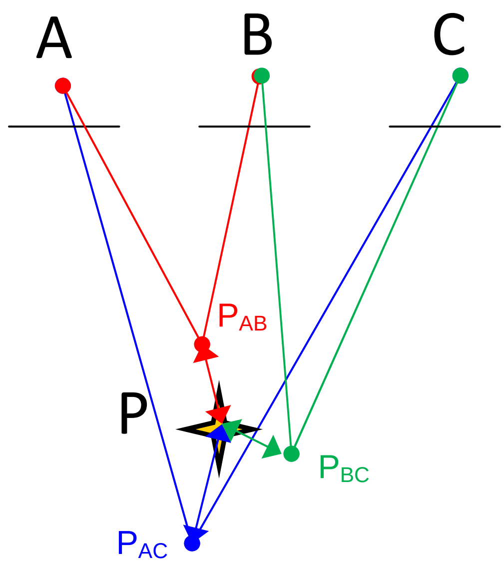

Figure 3. Concept of triplet restriction

4. EXPERIMENT

3.3 Data acquisition

In order to confirm the validity of the proposed simultaneous adjustment, data acquisition was performed in our test field. Test field has 117 GCPs, and 26 GCPs can be utilized in triplet area. GCPs were obtained by static observations using GPS that were set on the edge of road paints. Table 1 shows data component which used in this investigation, and Figure 4 shows the centre image using in this investigation. It was taken with about 1270 m, and photo scale is about 1/21,000. Therefore, GSD (Ground sampling distance) shows about 20cm.

Figure 5, 6 shows GCP image, and it can be realized that image quality is not clearly. Pointing were performed in each calibration with 1/1000 pixel accuracy, but it is speculated that pointing accuracy haven't 1/1000 pixel accuracy.

Domain	Item	Contents
Test field	All GCPs	117 points
Platform	Helicopter	AS-350BA
Flight	Speed	130 km/h
	Altitude	1270 m
GPS	Rate	1 sec
IMU	Rate	200 Hz
Laser	Scan rate	70 kHz
	Scan angle	40 degree (full)
Digital Camera	Focal length	60 mm
	Sensor size	9 x 9 μm
	Image size	5440 x 4080

Table 1. Data component

Figure 4. Centre image

Figure 5. GCP in Parking

Figure 6. Image quality

3.4 Accuracy Evaluation

Table 2 shows root mean square error for 26 check points, and permissible errors means restrictions for check points which are established by GSI in generating each scale map using direct-georeferencing system. RA (Relative Accuracy) means the value which was computed from equation (5)

$$RA = \frac{1}{\frac{H}{\sqrt{\sigma_x^2 + \sigma_y^2 + \sigma_z^2}}} \quad (5)$$

where H:Flight Height

σ:root mean square error for x, y, z

It can't be found significant differences between both calibration models, but it can be confirmed that the horizontal and vertical accuracy are improved by the simultaneous adjustment. Furthermore, it can be found that the both calibration accuracy compare with permissible error show less than 1/1000 and more than 1/5000. Consequently, it is concluded that calibration using pseudo GCPs is practical method in direct-georeferencing, and the accuracy was improved by triplet restriction.

Type	σ_x	σ_y	σ_z	RA
Using Pseudo GCPs	0.422	0.422	0.449	1/1701
Simultaneous adjustment	0.402	0.372	0.433	1/1819
Permissible error 1/500 1/1000 1/2500 1/5000	0.150 0.300 0.750 1.500	0.150 0.300 0.750 1.500	0.200 0.300 0.500 1.000	1/4356 1/2444 1/1083 1/542

H =1270m in RA

Table 2. RMSE for check points

5. CONCLUSION

In order to develop new calibration methods combined with GPS/IMU and Laser Scanner data, simultaneous adjustment was investigated in this paper.

It is confirmed that calibration using pseudo GCPs and simultaneous adjustment show less than 1/1000 and more than 1/5000 which is restricted by GSI in generating each scale map using direct-georeferencing system, and the accuracy was improved by triplet restriction.

Therefore, it is concluded that simultaneous adjustment using pseudo GCPs and triplet restriction is practical method in direct-georeferencing since the simultaneous adjustment have ability to perform interior and exterior orientation without any GCP nor aerial triangulation. However,

There are issues, however, for further work. These problems are improvement of accuracy and automatic generation of pseudo GCPs

REFERENCES

Baltsavias E, 1999. A comparison between photogrammetry and laser scanning, *ISPRS Journal of Photogrammetry and Remote Sensing*, Vol. 54, pp.83-94

Cramer M. and Stallmann D., 2002, System calibration for direct georeferencing, International Archives of Photogrammetry, Remote Sensing and Spatial Information Sciences 34 (2002) (Part 3A), pp. 79-84.

Ackermann F, Ebner H, Klein H, 1972, Combined block adjustment of APR Data and Independent Photogrammetric Models, *The Canadian Surveyor*, Vol. 26, pp.384-396.

EL-Hakim S.F., and Faig W, 1981, A combined Adjustment of Geodetic and Photogrammetric Observations, Photogrammetric Engineering and Remote sensing, vol.47, No.1, pp.93-99.

Chikatsu H., Kasugaya N., Murai S., 1988, An Adjustment of Photogrammetry Combined with the Geodetic Data and GPS, 16th International Society for Photogrammetry and Remote Sensing, Vol.26, 110-121.

Chikatsu H., and Odake T., 2006, Ubiquitous Digital Photogrammetry by Consumer Grade Digital Camera, International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences, Vol. XXXVI, PART 5 (CD-Rom), ISSN 1682-1750.

Fryer J.G and Brown D.C., 1986, Lens Distortion for Close-Range Photogrammetry, Photogrammetric Engineering and Remote Sensing, Vol.52, No.1, pp. 51-58.

Chikatsu H., 2007, Re-evaluation of interior orientation parameters of consumer grade digital camera in digital photogrammetry, 5th ARIDA SEMINAR on Innovations in 3D Modelling and Visualization of Digital Imagery-Based Spatial Information, http://www.chikatsu-lab.g.dendai.ac.jp/arida/cgi/webprotect/arida_workshop_5th/protect.cgi